



Hydraulic Evaluation of Discharge Over Submerged Rock Wing Dams on the Upper Mississippi River

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PURPOSE: This technical note presents prototype data and equations for predicting discharge over the top of submerged wing dams. This analysis was part of a study, done through the Corps of Engineers' Land Management System, to determine the impacts of zebra mussels on water quality and ecological conditions in the Upper Mississippi River (UMR).

BACKGROUND: Wing dams (also called spur dikes) are rock structures constructed perpendicular to the flow direction in a river. They extend part way across the channel from the riverbank and constrict flow to a narrower deeper channel more suitable for navigation. Originally constructed in the 1800s as emerged structures, wing dams on the UMR were permanently submerged when the locks and dams were constructed in the mid-1930's. Submergence and deterioration have decreased the effectiveness of wing dams; however, they remain a prominent factor in the river landscape. The low velocity zones and scour holes associated with wing dams provide aquatic habitat diversity, shelter, food organisms, and spawning substrate for a variety of fish species and are an important component of river habitat (Pitlo 1998, Shields 1995). Since wing dams are likely colonization sites for zebra mussels, quantifying the hydraulic conditions near them is important.

PROTOTYPE DATA: Hydraulic and geometric data at wing dams (Table 1) were collected in 1994 (Barrientos and Associates, Inc. 1995), using an acoustic doppler channel profiler. Mississippi River total discharge was available from each lock and dam, and the main channel discharge at each wing dam was determined based on available hydraulic data. Figure 1 shows typical flow patterns found at submerged wing dams. Because of the submergence of the wing dams (average depth = 6.8 ft) and subsequent flow over the top of the wing dams, significant lateral eddies were not observed, as they often are at emerged wing dams. Similar observations were made by Maynard in 1999.¹ In Pitlo's 1998 study of wing dams, an average water depth of 5.6 ft was found.

RELATIONSHIPS BASED ON PROTOTYPE DATA: Most research on wing dams has focused on the hydraulics of emerged wing dams or morphometric changes associated with wing dams¹ (Shields 1995, Zaghloul 1983) and the habitat that results (Pitlo 1998). Several equations that relate discharge over wing dams to channel and structure geometry are presented in Burch et al. (1984). These equations were developed to predict the effects of constructing wing dams and require estimating depth and channel width before and after construction. The goal of this study was to develop relationships that predict wing dam discharge (i.e. discharge over the top of a submerged wing dam) as a function of easily measured geometric parameters. Prototype data from Table 1 were plotted in Figures 2 and 3. Figure 2 indicates that the ratio of wing dam discharge to main channel discharge is proportional to the ratio of wing dam area to main channel area. Figure 3 indicates that

¹ Personal communication, 1999, Dr. Stephen Maynard, Research Hydraulic Engineer, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS.

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Table 1
Hydraulic and Geometric Data at Wing Dams

Pool	River Mile	Wing Dam	Measured Flow Q_{wd} (cfs)	Main Channel Flow Q_{mc} (cfs)	Total Flow Q_t (cfs)	Avg. Depth h (feet)	Wingdam Flow Area A_{wd} (feet ²)	Main Ch. Flow Area A_{mc} (feet ²)	Wingdam Length L_{wd} (feet)	Main Channel Width W_{mc} (feet)	Approx WSEL
4	756.9L	55	2184	33693	37900	5.4	1420	15380	264.78	1480	667.60
4	756.9R	117	1778	33693	37900	6.4	1505	15380	232	1480	667.60
4	756.8L	56	2154	33693	37900	4.8	1284	13237	267.16	1625	667.60
4	756.8R	118	3108	33693	37900	5.5	2048	13237	371.03	1625	667.60
4	756.6L	57	1479	33693	37900	4.9	540	14807	110.57	1825	667.57
4	756.6R	119	1657	33693	37900	6.9	1254	14807	190.15	1825	667.57
5	749.1R	42	767	33550	42300	4.7	687	15480	142.79	1275	669.75
5	749.0R	43	1789	33550	42300	5.6	1204	15674	217.86	1360	669.50
5	748.8R	44	2006	33550	42300	6.0	941	15106	155.89	1450	669.00
5	748.7L	45	3383	33550	42300	5.6	1365	15293	242.05	1210	669.00
5	748.5R	36	2080	33550	42300	5.7	1334	15447	236.66	1065	669.00
5	740.5R	26	1055	50600	50600	7.3	781	22020	105.76	1800	660.00
5	740.4R	25	3716	50600	50600	8.7	2261	21404	251.6	2000	660.00
5	740.2R	4	6067	50600	50600	7.9	4001	22935	493.62	2400	660.00
5	740.1R	29	4461	50600	50600	9.1	2294	23852	241.82	2400	660.00
5	740.0R	A	15000	50600	50600	8.2	8986	31532	1074.13	2300	659.95
5	739.9R	33	22451	50600	50600	9.9	15486	32918	1543.32	2300	659.95
5	739.8R	34	28148	50600	50600	8.5	9738	32016	1131.13	2300	659.95
5	739.1L	B	8004	50600	50600	8.7	4783	29636	542.9	2100	659.80
5	739.0L	39	11579	51000	51000	10.1	7643	35995	745.64	2500	659.70
3	805.7R	29	4772	22600	22600	6.1	1584	11178	263.52	1090	675.90
3	805.6R	30	3870	21100	21100	4.8	1750	10967	388.55	1110	675.60
3	805.5R	1	2335	21100	21100	5.7	2056	10683	362.93	1025	675.60
7	708.9L	76	15340	51641	51900	6.6	5961	26335	897.23	2150	640.35
7	708.9R	24	5996	51641	51900	7.0	2642	26335	375.51	2150	640.35
8	690.7L	34	1550	41198	55900	4.6	1195	7559	258.15	1825	632.36
8	689.0L	55	8894	30577	55900	7.8	4234	11858	542.04	1575	632.20
9	664.7R	C	3020	29998	56600	6.2	1405	12444	226.75	1160	621.31
9	664.6R	D	2914	27338	56600	7.4	1352	9081	180.31	960	621.28
9	664.4R	E	1290	24678	56600	6.1	1057	8779	174.3	940	621.22
9	664.2L	F	1705	24678	56600	6.8	964	9365	141.56	950	621.16
9	664.1L	G	2936	24678	56600	6.3	1623	10679	257.16	925	621.13
9	663.9L	H	4482	24281	56600	5.9	1457	10679	251.94	950	621.10
10	644.6R	I	2552	34440	56000	9.1	1188	8609	129.84	1175	616.62
10	644.5R	J	585	34440	56000	8.4	495	8609	59.12	1170	616.60
10	644.4L	6	3657	34440	56000	7.1	1555	11750	221.82	1135	616.57
10	644.3L	5	3290	34440	56000	8.0	1598	11856	200.69	1000	616.55

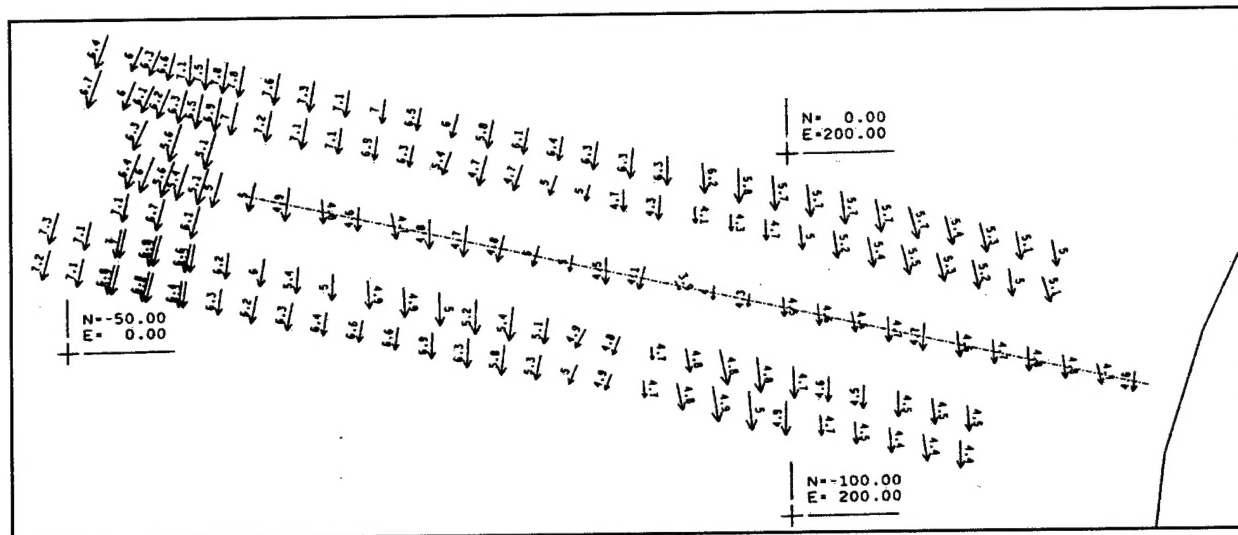


Figure 1. Typical flow direction (shown by arrow), velocity (shown by arrow length), and water depth (designated by numbers) at submerged wing dams (shown by dashed lines)

the ratio of wing dam discharge to main channel discharge is also strongly related to the ratio of wing dam length to main channel width.

The following two equations provide the best estimate of flow over submerged wing dams.

$$Q_{wd} / Q_{mc} = 0.98 A_{wd} / A_{mc} - 0.019, \quad r^2 = 0.82$$

$$Q_{wd} / Q_{mc} = 0.69 L_{wd} / W_{mc} - 0.030, \quad r^2 = 0.84$$

where

Q_{wd} = discharge over wing dams, cfs

Q_{mc} = discharge in main channel, cfs (includes wing dam discharge)

A_{wd} = flow area over wing dams, ft^2

A_{mc} = flow area in main channel, ft^2 (includes wing dam area)

L_{wd} = length of wing dam, ft

W_{mc} = main channel width, ft (includes wing dam length)

The first equation is probably more accurate for a full range of discharge conditions since it accounts for cross-sectional area. However, the second equation has more utility since wing dam length can be obtained from maps or aerial photographs. The constant 0.69, in the second equation, is directly related to the average ratio of wing dam depth to main channel depth found in the prototype data. If wing dam submergence is beyond the range of depths (5 to 8 ft) encountered in this study, the relationship based on length should be adjusted.

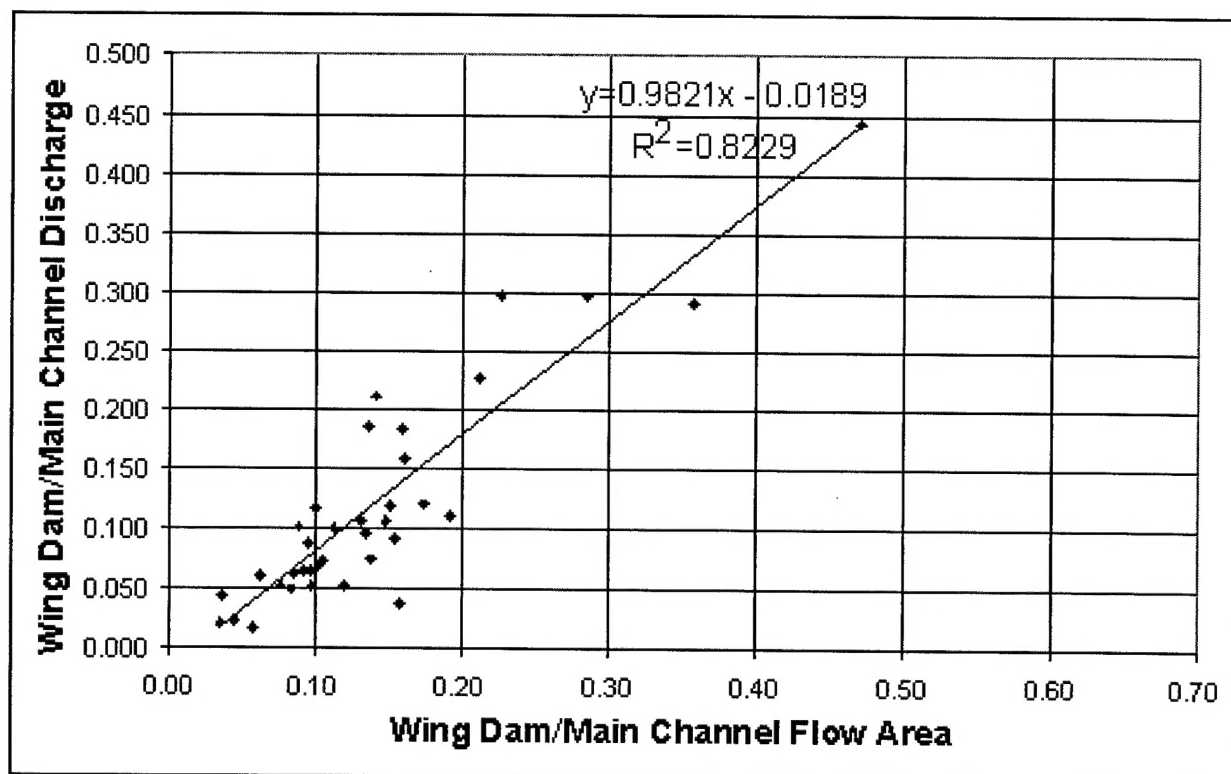


Figure 2. Wing dam discharge based on the ratio of wing dam flow area to main channel flow area

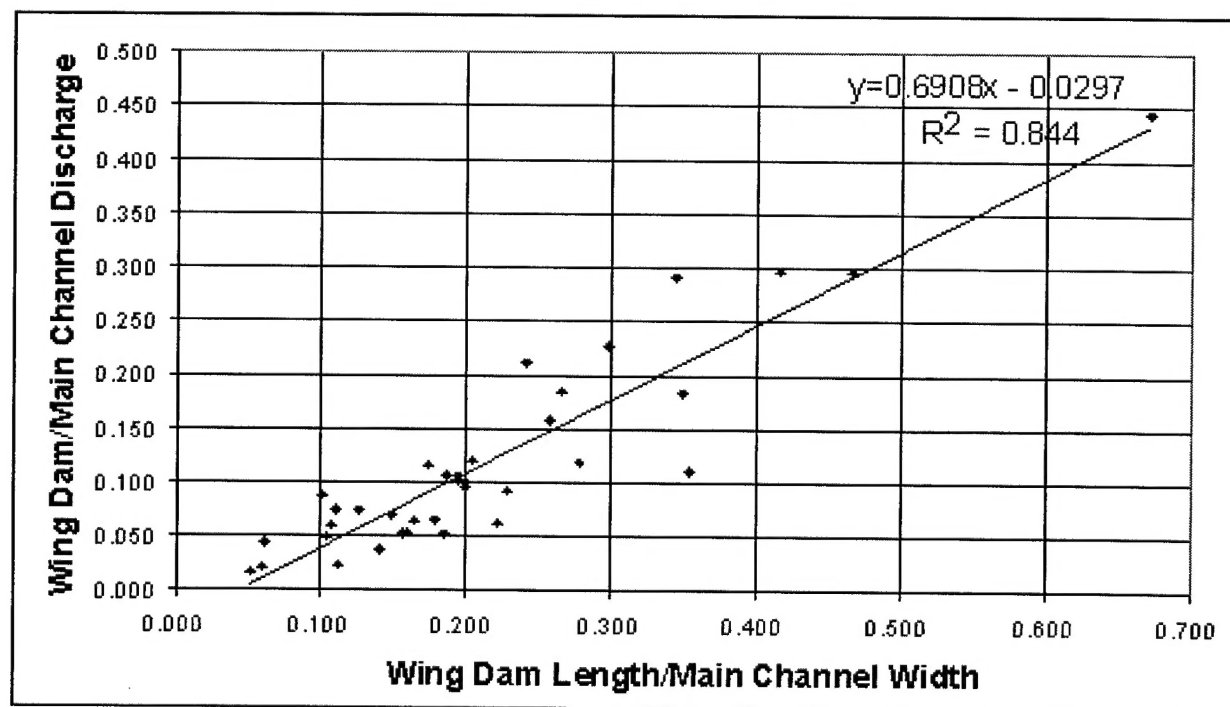


Figure 3. Wing dam discharge based on the ratio of wing dam length to main channel width

CONCLUSIONS: This analysis was initiated because of interest in the effects of zebra mussels on water quality in the Upper Mississippi River. Given that the rock substrate associated with wing dams is conducive to colonization by zebra mussels, quantifying the amount of water conveyed over wing dams was essential. The two equations developed above allow the calculation of wing dam discharge. These equations also can be used in other mass transport studies, which require knowledge of the flow distribution within a river channel or floodplain, or in various types of river management studies.

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Hendrickson, J. S., and Schneider, M. J. (1999). "Hydraulic evaluation of discharge over submerged rock wing dams on the Upper Mississippi River," *Water Quality Technical Notes Collection* (WQTN PD-06), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/elpubs/wqtncont.html

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